

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of)	
)	
Fostering Innovation and Investment in)	GN Docket No. 09-157
the Wireless Communications Market)	
)	
A National Broadband Plan For Our)	GN Docket No. 09-51
Future)	

**REPLY COMMENTS OF THE
NATIONAL ACADEMY OF SCIENCES'
COMMITTEE ON RADIO FREQUENCIES**

The National Academy of Sciences, through the National Research Council's Committee on Radio Frequencies (hereinafter, CORF¹), hereby submits its comments in response to the Commission's August 27, 2009, Notice of Inquiry in the above-captioned dockets (NOI). CORF notes that the initial comments in response to the NOI did not address the passive scientific use of the spectrum. Thus, CORF discusses herein the unique value, innovation and vulnerability of passive scientific use of the spectrum, and the impact on issues of interference protection and spectrum efficiency raised in the NOI.

I. Introduction: The Unique Value, Innovation and Vulnerability of Passive Scientific Use of the Spectrum.

A. What Passive Users of the Spectrum Do, and the Value of That Work.

CORF has a substantial interest in the spectrum issues raised in this proceeding, because CORF represents the interests of the *passive* scientific

¹ A roster of the committee members is attached.

users of the radio spectrum,² including users of the Radio Astronomy Service (RAS) and Earth Exploration Satellite Service (EESS) bands. RAS and EESS observers perform extremely valuable research and provide data of national importance.

As the Commission has long recognized, radio astronomy is a vitally important tool used by scientists to study our universe. It was through the use of radio astronomy that scientists discovered the first planets outside the solar system, circling a distant pulsar. Radio astronomy has also enabled the discovery of organic matter and prebiotic molecules outside our solar system, leading to new insights into the potential existence of life elsewhere in our galaxy. Measurements of radio spectral line emission have identified and characterized the birth sites of stars in our own galaxy, the processes by which stars slowly die, and the complex distribution and evolution of galaxies in the universe. Radio astronomy measurements have discovered fluctuations in the cosmic microwave background, generated in the early universe, which later formed the stars and galaxies we know today. It has established the existence of a black hole in our galactic center, a phenomenon that may be crucial to galaxy formation. Observations of supernovas have allowed researchers to witness the creation and distribution of heavy elements essential to the formation of planets like Earth, and of life itself.

The Commission has also long recognized that satellite remote sensing, including sensing by users of the EESS, is a critical and unique resource for

² "Passive" use of the spectrum means observing the presence of certain naturally occurring phenomena on specific frequencies, rather than using spectrum to transmit information or signals. The latter would be active use of the spectrum.

monitoring characteristics of the global atmosphere, land, and oceans. For certain applications, satellite-based microwave remote sensing represents the only practical method of obtaining atmospheric and surface data for the entire planet. EESS data have contributed substantially to the study of meteorology, atmospheric chemistry, climatology, and oceanography. Currently, instruments operating in the EESS bands provide regular and reliable quantitative atmospheric, oceanic, and land measurements to support a broad variety of scientific, commercial, and government (civil and military) data users. Major governmental users of EESS data include the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation, the National Aeronautics and Space Administration (NASA), the Department of Defense (especially the U.S. Navy), the Department of Agriculture, the U.S. Geological Survey, the Agency for International Development, the Federal Emergency Management Agency, and the Forestry Service.

B. Technical Innovation by Passive Users, and Spin-Off Technologies.

Because scientific discoveries are usually made at the limits of instrumental sensitivity, radio astronomy and satellite remote sensing have contributed significantly to the development of innovative wireless technologies. Indeed, the discovery of radio emissions from celestial objects (the basis of Radio Astronomy) was made in 1932 by a scientist at a center for technological innovation—Bell Labs. Karl Jansky's discovery was a by-product of his studies of system and thermal noise in radio communications systems.

Since that time, Radio Astronomy and Satellite Remote Sensing have been copious sources of innovative technologies and algorithms. While these innovative technologies are originally applied purely for scientific research, they have often been copied or spun off into valuable uses in a variety of other sectors, especially *health care, national security, public safety, navigation, and telecommunications*.³ Some examples are listed below:

- Originally developed as a radio astronomical technique for the high-resolution imaging of astronomical objects, very long baseline interferometry (VLBI) has been used for applications in Earth science—for example, the determination of geophysical parameters used in studying plate tectonics, polar wandering, latitude measurements, variations in Earth's rotation, and the *identification of potential earthquake zones* through the precise measurement of fault motion.
- The VLBI reference frame of celestial coordinates, based on extremely distant radio sources, is fundamental to the periodic *calibration of the GPS reference clocks*.
- Pulsar observations, VLBI, and applications of Einstein's general theory of relativity play a major role in precision *navigation and geodesy*—including that of spacecraft—and timekeeping.
- *Computerized x-ray tomography (CT scans)* employs software and methods originally developed for mapping radio astronomy sources. Radio astronomers have also adapted their methods of measuring microwave temperature for the noninvasive detection of tumors and other regions of vascular insufficiency. Microwave sensors have poorer angular resolution than infrared ones do but are more sensitive to deep-tissue temperatures. The combination of microwave and infrared thermographic data provides a true-positive detection rate of 96 percent, better than either alone, for breast cancer.⁴
- The data-intensive computing and storage systems that have been developed for signal processing in areas such as pulsar and SETI searches have had wide applications in voluntary distributed

³ National Research Council, *Working Papers: Astronomy and Astrophysics Panel Reports*, National Academy Press, Washington, D.C., 1991, p. 307.

⁴ Ibid.

computing projects. For example, the Berkeley Open Infrastructure for Network Computing open source volunteer computing platform, which was created to analyze the vast amount of data collected for the SETI Project, currently engages its volunteers in scientific supercomputing projects including climate modeling/global warming studies, drug research for HIV, malaria and cancer, protein folding, gravity waves, particle physics, and many others.

- Low noise receiver and signal analysis technology developed for radio astronomy has been used in implementing the *Enhanced 911 emergency service*.
- Development of millimeter and submillimeter radiation sources and detectors for radio astronomy and remote sensing has fostered the field of Terahertz spectroscopy and its important *Homeland Security applications in imaging (including airport security) and poisonous gas detection*.
- Innovative applications of satellite remote sensing (EESS) data include weather forecasts for use in *military and civilian aviation and sailing; hurricane and severe storm warning and tracking; flood monitoring; and seasonal and interannual climate forecasts and monitoring*. Use of satellite remote sensing data is critical to the study of *global climate change*.

C. The Unique Vulnerability of Passive Observation to Interference.

The critical science undertaken by RAS and EESS observers, and the resulting technological innovations, cannot be performed without access to interference-free spectrum. The emissions that radio astronomers receive are extremely weak—a radio telescope receives only about one-billionth of one-billionth of a watt (10^{-18} W) from a typical cosmic object. Because radio astronomy receivers are designed to pick up such remarkably weak signals, radio observatories are particularly vulnerable to interference from in-band emissions, spurious and out-of-band emissions from licensed and unlicensed users of neighboring bands, and emissions that produce harmonic signals in the

RAS bands. Even weak, distant in-band man-made emissions can preclude RAS use. Like radio astronomers, remote-sensing scientists have little control over the frequencies at which they must observe in order to fulfill their scientific missions—the specific frequencies of specific atoms, ions and molecules are established by the laws of physics and chemistry. Similarly, since remote-sensing scientists observe the noise floor itself and extremely weak variations therein, their observations are also very vulnerable to interference from man-made transmissions.

In summary, because of the passive nature of this use of the spectrum and the extremely weak signals observed, passive scientific use of the spectrum is uniquely vulnerable to interference from other services. Interference protection is discussed below.

II. Protection From Interference

A. CORF Supports the Use of Quantifiable Criteria in Measuring Interference.

The NOI notes at paragraph 34 that the Commission's rules define interference with a somewhat subjective standard ["endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service."]. The NOI asks what quantifiable criteria should be used in evaluating interference complaints.

It is not in CORF's purview to advise on interference between active services, so these Reply Comments will discuss only interference to passive services. In that regard, while CORF recognizes that there are some benefits of

a more flexible subjective approach to evaluating interference, there are obvious advantages to using an objective, quantifiable standard: clarity, certainty, verifiability, and testability. The International Telecommunications Union (ITU) has already established objective, quantifiable criteria for defining interference to passive users of the spectrum, as well as for measuring such interference. The RAS and the EESS each have ITU Recommendations that provide criteria for such protection. ITU-R RA.769 (and its predecessor, CCIR 224) covers the RAS for most cases, and has been in place for many decades. It has been supplemented more recently for the specific case of non-geostationary satellites by ITU-R RA.1513. The corresponding EESS Recommendation is ITU-R RS.1029. These Recommendations contain sufficient information for system design engineers to quantify the required filters (if any) to provide suppression of unwanted emission in passive service bands.

CORF suggests that the Commission adopt such an objective, quantifiable approach in connection with interference protection for passive users of the spectrum. The Commission may also want to consider taking such an approach (with reference to published ITU standards where applicable) in connection with evaluation of interference between active users of the spectrum.

**B. The Commission Should Be Cautious in Attempts to
Promote Efficiency by Regulating Receiver Performance.**

The NOI also seeks comments on promoting efficiency by regulating receiver performance. Notably, footnote 37 suggests that if an incumbent user of the spectrum continues to use “outdated [receiver] equipment,” the Commission’s rules could provide a reduced level of interference protection to the incumbent, in

order to allow other services to make more intensive use of the spectrum. As discussed below, CORF urges the Commission to be cautious in any such action, at least as applied to passive users.

Innovations in receiver design and technology can indeed help to mitigate interference. Both the radio astronomy and Earth remote sensing communities have been investigating and testing digital technologies to mitigate interference, such as using time-frequency blanking or active signal cancelation, for example. Despite such advances, these unilateral mitigation techniques do not and cannot solve the interference problem, and can incur significant additional expense on projects. Thus, receivers must rely heavily on frequency selectivity to avoid interference. Because these receivers are measuring natural radio emissions (what amounts to “noise” to other users), other techniques such as modulation coding are not available to enhance selectivity and reduce the effects of interference. CORF suggests that these factors be considered and that no provision be implemented to reduce protection from interference to the passive services.

Of equal concern is the determination of what constitutes “outdated” equipment. Radio astronomy and Earth remote sensing product lifecycles can be quite extended. For example, development periods can extend to five years or longer, and operations can easily exceed a decade. And, once EESS receivers are launched into space, they cannot be replaced without launching another satellite. Thus, a “state-of-the-art” receiver in present use by the passive services could be based on decade-old technology. CORF suggests that if such

a provision were adopted, then a Service's fiscal and technological realities be considered in objectively determining the definition of "outdated" equipment.

III. "Efficient" Uses of the Spectrum, and Band Sharing.

In para. 40, the NOI notes different possible definitions of efficiency, including "spectrum efficiency" (transmitting the maximum amount of information within the least amount of spectrum), "technical efficiency" (deploying inputs, such as spectrum, equipment, capital, and labor, to generate the most output for the least cost), and "economic efficiency" (using spectrum resources to generate the highest value to the public). CORF has always supported efficient use of the spectrum, and notes that use of the spectrum for passive scientific observation is not only use of the spectrum, but also spectrally and economically efficient use of the spectrum.

A. Passive Scientific Observation of the Spectrum Constitutes "Use" of the Spectrum.

In evaluating what constitutes the efficient use of spectrum, it is essential for the Commission to recognize that passive scientific observation of the spectrum constitutes "use" of the spectrum. Such use has wide regulatory recognition. The numerous allocations to RAS and EESS in the domestic and international tables of allocations demonstrate that the FCC and the International Telecommunication Union both recognize that RAS and EESS constitute use of the spectrum equal to that of active services. Indeed, many of the allocations to RAS and EESS are as the primary and sole service in that particular band. See, e.g., the Table of Allocations in Section 2.106 of the Commission's rules at 73-

74.6 MHz, 1400-1427 MHz, 1660.5-1668.4 MHz, 2690-2700 MHz, and 4990-5000 MHz.

In addition to frequency allocations, the FCC has recognized the importance of passive use of the spectrum in other regulations. Examples of geographic protection include Section 1.924(a) of the Commission's rules, which creates a National Radio Quiet Zone designed to protect the National Radio Astronomy Observatory in Green Bank, West Virginia, from interference. Section 1.924(d) of the Commission's rules similarly establishes notification requirements for a "Puerto Rico Coordination Zone" designed to protect radio astronomy at the Arecibo Observatory.⁵ Non-geographic-based protection for passive services is established in numerous other Commission rules. For example, Section 15.205 of the rules prohibits intentional emission of radiation from unlicensed devices in a number of bands allocated to passive services, including 13.36-13.41 MHz, 25.55-25.67 MHz, 38.0-38.25 MHz, 73-74.6 MHz, 401-403 MHz, 608-614 MHz, 1400-1427 MHz, 1660.5-1668.4 MHz, 2690-2700 MHz, 4.5-5.15 GHz, and 5.35-5.46 GHz.

B. Passive Scientific Observation is a Spectrally Efficient and Economically Valuable Use of the Spectrum.

1. *Passive Scientific Observation is an Efficient Use of the Spectrum.*

Scientific use of the RAS and EESS bands is done in a very spectrum-efficient manner. The natural sources of radiation measured by passive EESS applications are extremely low power relative to the signals generated and

⁵ See also, Amendment of the Commission's Rules to Establish a Radio Astronomy Coordination Zone in Puerto Rico, Report and Order, 12 FCC Rcd 16522 (1997).

received by active services. As a result, observation over the entire allocated bandwidth is often required for accurate measurements. Observed phenomena tend to be globally distributed as well, and observations are required on short time scales; given the number of EESS assets currently in use, each point on Earth is observed in a passive allocation multiple times each day, 7 days per week.

The natural sources of radiation measured by passive *RAS* applications are also extremely low power relative to the signals that are generated and received by active services. The entire allocated bandwidth is usually needed for sufficiently sensitive observations of the broadband sources. The narrowband sources (e.g. the 1420 MHz emission line of neutral hydrogen) have varying apparent frequency depending on the motion of the emitting atoms, ions, or molecules. Thus observations of the narrowband sources typically use the entire allocated bandwidth to measure the change with frequency of the emission line over the field of interest (e.g. a rotating galaxy). Radiotelescopes observe continually, are spread across all continents, and observe with extreme sensitivity over the entire allocated bandwidth. As a result, *RAS*' full use of the spectrum constitutes very efficient use of the spectrum.

It also should be noted that scientific observation in the passive bands constitutes efficient use in the sense that no observer prevents any other party from observing on the same frequency. Indeed, there is virtually no limit to the number of parties that can observe on the same frequency, even at the same time, and cause no interference to one another.

2. *Passive Use Is a Valuable Use of the Spectrum.*

The value of the science performed by passive users of the RAS and EESS bands can in some cases be measured directly, and in those cases, the value is great. In other cases, the value of such science can be measured only indirectly, but that value is no less as a result.

Satellite remote sensing is one of the cornerstones of meteorology, oceanography, climatology, and environmental science, supporting analysis and research that provide assessments, forecasts, and warnings to the public. Weather- and climate-sensitive industries account for about a quarter of the U.S. gross domestic product. It has been estimated that the average impact on the U.S. economy of year-to-year weather and climate changes is \$100 billion in year-2007 dollars.⁶ Droughts, severe storms, and floods alone account for more than \$20 billion in damage annually in the United States. The impact on the U.S. economy of an El Niño event is estimated at \$25 billion.⁷ Without satellite remote sensing, the ability of the atmospheric and oceanic science community to monitor, analyze, and predict environmental conditions would be drastically diminished. These satellites provide a critical means of obtaining accurate and

⁶ See, Irving Leveson, *NPOESS Civil Benefits and Contributions to U.S. Economic and Environmental Security*, report to the NPOESS Integrated Program Office, April 24, 2007, pp. 21-22; as cited in Irving Leveson, *NPOESS Economic Benefits, Final Report*, June 18, 2008, p. 15 ("Final Report"), available at www.economics.noaa.gov/bibliography/npoess-report.doc, last accessed June 2, 2009. The value to the U.S. economy of the NPOESS program alone over its service life is estimated at approximately \$9 billion to \$16 billion in present-value dollars. Final Report at Table 4, p. 24.

⁷ Stanley A. Changnon, Gerald D. Bell, David Changnon, Vernon E. Kousky, Roger A. Pielke, Jr., and Lee Wilkins, *El Niño. 1997-1998: The Climate Event of the Century*, Oxford University Press, New York, 2000.

frequent assessments of certain aspects of land- and sea-surface and atmospheric conditions on a global scale.

The potential loss of any critical band for the EESS could be expected to result in significant costs to society, resulting from reduced ability to forecast weather and the environment, manage resources, and monitor and predict disruptive climate changes, both natural and anthropogenic. The costs of severe weather events alone are often in the hundreds of millions of dollars per event. NOAA's National Weather Service forecasts, warnings, and the associated emergency responses have been estimated to result in a \$3 billion savings in a typical hurricane season. Two-thirds of this savings, \$2 billion, is attributed to the reduction in hurricane-related deaths, and one-third of this savings, \$1 billion, is attributed to a reduction in property-related damage because of preparedness actions.⁸ Errors in temperature and precipitation forecasting for even relatively benign meteorological events such as local or regional heat or cold waves can cost U.S. utilities approximately \$1 million per degree Fahrenheit daily as a result of an impaired ability to match energy supplies with demand.⁹ Similarly, benefits to U.S. agriculture by altering planting decisions based on improved El Niño forecasts have been estimated at \$265 million to \$300 million annually, throughout El Niño, normal, and La Niña years. Costs associated with errors in

⁸ National Oceanic and Atmospheric Administration, *Economic Statistics for NOAA*, 5th Ed., April 2006.

⁹ Ibid.

predicting the onset of regional climate changes could thus easily amount to hundreds of millions of dollars per year.¹⁰

While it is difficult to ascribe forecast errors to interference occurring within any specific microwave band, it is noted that undetected interference in any passive microwave band can seed the growth of large errors in numerical weather-prediction models. The costs of such forecasting errors are typically largest in areas of highest population density and thus of greatest spectral demand.

The value of the radio astronomy performed by users of the RAS band must generally be measured more indirectly than that of satellite remote sensing, but that value is no smaller as a result. The scientific truths learned through radio astronomy about our universe—its origins, the physical forces that shape it, the prebiotic chemistry that occurs in it, and its ultimate destiny—are the priceless cultural heritage of all humanity. One measure of the value of radio astronomy is the four Nobel Prizes awarded for contributions to science made by radio astronomers.¹¹ This includes awards for the discovery of the first pulsar in a binary system, leading to important confirmation of Einstein's theory of gravitational waves; and the discovery of cosmic background microwave radiation, which was primary evidence for the "Big Bang" theory of the creation of the universe.

C. Shared Use of Passive Allocations.

¹⁰ National Oceanic and Atmospheric Administration, *Economic Statistics for NOAA*, 5th Ed., April 2006.

¹¹ See, National Research Council, *Handbook of Frequency Allocations and Spectrum Protection for Scientific Uses*, The National Academies Press, Washington, D.C., 2007, p. 11.

While CORF recognizes that shared use of spectrum can promote efficiency, there are special problems involved in shared use of spectrum allocated to passive users. Comment deadlines and the complexity of issues in this proceeding constrain the ability of CORF to provide an extensive analysis, but CORF would like to direct the FCC to a U.S. National Research Council report released on November 2, 2009 that reviews in-depth the possibility of sharing the spectrum, and of a spectral monitoring system, in addition to many other aspects of the passive science services.¹² In addition to the material presented in *Spectrum Management for Science in the 21st Century*, CORF notes the following in response to the FCC inquiry regarding shared use.

The Radio Astronomy results produced over the past sixty years, including work that produced four Nobel prizes, depend on collecting extremely faint celestial radiation. Typical 'strong' calibrators provide a billionth of a billionth of a watt per square meter per MHz. The faintest signals detected are a few times a billionth of this level. Cryogenically cooled receivers, very large apertures and long integration times, together with modern signal processing techniques, are necessary to make this research feasible. As a result, coexistence with man-made sources of radiation is possible only when unwanted (spurious and out of band) emission is strictly limited. Shared use of a band is not feasible within line of sight, but can be effective with more distant transmitters through coordination. We note further that broad bandwidth observations will become important in the

¹² National Research Council, *Spectrum Management for Science in the 21st Century*, The National Academies Press, Washington, D.C., 2009. For spectrum sharing, see pp. 126-131, and 137-142. For spectral monitoring, see pp. 104-108, 117, and 136-137. Available at http://www.nap.edu/catalog.php?record_id=12800.

future as radio observatories probe the very early Universe¹³ for the first time and extreme natural phenomena such as pulsars¹⁴ that can only be observed at certain frequencies. There is currently limited protection against RFI at these frequencies, and RAS observations will require a means to access quiet windows.

Remote sensing measurements are also affected by unwanted emission. Airborne and satellite earth sensors measure very small variations in the effective thermal temperature of the earth's surface, of the order of a billionth of a billionth of a Watt per MHz (10^{-18} W/MHz) or less. This level of precision and sensitivity is required to accurately extract key environmental parameters, including atmospheric temperature and humidity, sea ice extent, winds over the ocean, rain, soil moisture, snowfall, and sea surface temperature and salinity.¹⁵ Such information is critical in weather prediction and climate studies, among others.

As noted above, band sharing between passive and active services can be feasible, in carefully chosen cases. There has been at least one example of successful sharing—RAS and wireless medical telemetry in the 608-614 MHz band. Reasons for success in this case include the extremely low power of wireless telemetry equipment, and a requirement for licensing and coordination per CORF's recommendation.¹⁶

¹³ Observations would be at frequencies between 30 and 300 MHz.

¹⁴ Observations would be at frequencies below 1400 MHz.

¹⁵ National Research Council, *Handbook of Frequency Allocations and Spectrum Protection for Scientific Uses*, The National Academies Press, Washington, D.C., 2007, p.11.

¹⁶ National Academy of Sciences' Committee on Radio Frequencies, *In the Matter of Amendment of Parts 2 and 95 of the Commission's Rules to Create a Wireless*

In paragraph 47 of the NOI, the Commission asks whether the noise floor is increasing, and whether such an increase has an impact on wireless innovation. While CORF has no documented evidence to provide at this time, it is the experience of many passive scientific users of the spectrum that the noise floor (at least at 1-2 GHz and below) generally has been increasing significantly in recent years. Any such increase has a detrimental impact on the innovative use of the spectrum by passive scientific observers, since the nature of that observation is often of minor variations in the noise floor or even the value of the noise floor itself, so CORF supports any measures the FCC would take to reduce the active noise floor.¹⁷

Lastly, in paragraph 66 of the NOI, the Commission asks whether research institutions such as universities should be allowed to operate experimental stations without the obligation to coordinate the use of frequencies, on the condition that they do not cause interference to “authorized stations.” CORF is concerned that such a condition could be interpreted to allow “experimental” interference with protected passive observations. Accordingly, if the Commission adopts such a policy, it should prohibit uncoordinated experimental operations on passive frequency bands that have primary allocation status, or are otherwise protected in the Commission’s rules from interference.

Medical Telemetry Service, ET Docket No. 99-255, filed September 30, 1999; available at http://sites.nationalacademies.org/BPA/BPA_048830.

¹⁷ In footnote 50 of the NOI, the Commission raises the idea of using frequency sensors to monitor the noise floor in particular areas. CORF supports such a proposal, at least in areas of significant interest to passive scientific observers. CORF’s members have substantial experience in the technologies that would be used to do such monitoring, and would be eager to assist the Commission in designing such a monitoring program. Furthermore, the aforementioned NRC report, *Spectrum Management for Science in the 21st Century*, pp.104-108, 117, and 136-137, discusses this proposal.

IV. Conclusion.

CORF supports the efficient use of spectrum, including the current practices of passive scientific observation of the spectrum. In order to promote such efficiency, CORF suggests that the Commission adopt an objective, quantifiable approach in connection with interference protection for passive (and where appropriate, other) users of the spectrum. The Commission should be cautious, however, in attempts to promote efficiency by regulating receiver performance, at least as applied to passive users.

Respectfully submitted,

NATIONAL ACADEMY OF SCIENCES'
COMMITTEE ON RADIO FREQUENCIES

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